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Power Quality Improvement of Wind Energy by Statcom

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ABSTRACT

Renewable energy sources are alternative energy source, can bring new challenges when it is connected to the power grid. When the wind power is connected to an electric grid affects the power quality. The effects of the power quality measurements are-the active power, reactive power, variation of voltage, flicker, harmonics, and electrical behavior of switching operations. The installation of wind turbine with the grid causes power quality problems are determined by studying this paper. For this Static Compensator (STATCOM) with a battery energy storage system (BESS) at the point of common coupling to mitigate the power quality problems. The grid connected wind energy generation system for power quality improvement by using STATCOM-control scheme is simulated using SIMULINK in power system block set. This relives the main supply source from the reactive power demand of the load and the induction generator in this proposed scheme. The paper study demonstrates the power quality problem due to installation of wind turbine with the grid. Also The improvement in power quality on the grid has been presented here according to the guidelines specified in IEC-61400 standard (International Electro-technical Commission) provides some norms and measurement

Keywords : International Electro-technical Commission (IEC), STATCOM, Battery Energy Storage System (BESS), Total Harmonic Distortion (THD), and Point of Common Coupling (PCC) wind generating system (WGS).

I. INTRODUCTION

Now a days energy demand is increasing rapidly, due to the growth in population and economic development in the world leading to increase in environmental impact on conventional plants. Hence renewable energy resources must be employed in order to meet the energy demand and have communal development and prolong growth. In recent years, among the other renewable energy sources, wind energy is gaining ever increasing attention as a clean, safe and economical resource. Thus to exploit wind power effectively its grid connection is necessary so as to realize its potential to significantly mitigate present day problems like energy demand along with atmospheric pollution. But amalgamation of wind power to grid introduces power quality issues, which predominantly consist of voltage regulation and reactive power compensation. The power quality is a crucial customer-focused measure and is of prominent importance to the wind turbine. The main power quality issues are voltage, current and frequency that results in mal-operation of customer end equipments. Wind turbine produces a continuously variable output power during its normal operation because of wind variation, effect of tower shadow, wind shear, turbulence. Voltage sag, swell ,flickers, harmonics etc. are the power quality issues which are more harmful to wind generation, transmission and distribution network i.e. for grid.

In wind power based generation, mostly induction generators are used because of its cost effectiveness and robustness. Induction generators draw reactive power from the grid for magnetization to which they are connected. The active power generated by induction generated is varied due to fluctuating nature of wind and this variation can prominently affect the absorbed reactive power and terminal voltage of induction generator. Integration of wind energy into grid affects the power quality of system.

The devices used for mitigation of power quality problems are known as Customer Power Devices (CPDs). The generalized compensating devices are: Dynamic Voltage Regulator (DVR), Static VAR Compensator (SVC), Static Synchronous Compensator (STATCOM), and Unified Power Quality Conditioner

(UPQC). Among all these devices performance of STATCOM with battery energy storage system (BESS) is very good and user friendly to mitigate the power quality issues.

- Support the reactive power to wind turbine and non-linear load from STATCOM.
- For fast dynamic response bang-bang controller is implemented in STATCOM
- Minimize the THD percentage at the PCC waveform

For improving the power quality of wind generating system as powered STATCOM based control technology has been proposed. A STATCOM is connected at common coupling point (PCC) along with solar power feed battery energy storage system (SBESS) to make the source current harmonic free and to improve the system performance. There are different control techniques available for STATCOM operation like, p-q theory, SPWM, d-q theory etc. In d-q theory reference currents are directly obtained from load currents without consideration of source voltage so that reference signals are not affected by voltage unbalance or distortion. This will increase the compensation robustness and performance. The proposed STATCOM along with hysteresis current control scheme for grid connected wind energy generation for improving the power quality has following objectives.

II. METHODS AND MATERIAL

POWER QUALITY IMPROVEMENT

A. Power quality standards, issues and its consequences

1. International electro technical commission guidelines:

Some guidelines of measurements and norms are specified under IEC 61400 standard which determines the power quality of wind turbines.
The standard norms are specified.

- IEC 61400-21: Measuring the power quality characteristic of grid connected wind turbine.
- IEC 61400-13: Wind Turbine—measuring procedure in determining the power behavior.
- IEC 61400-3-7: Measures the emission limits for fluctuating load and IEC 61400-12: Wind Turbine performance.

2. Harmonics

It is due to the operation of power electronic converters. Harmonic voltage and current should be in limited as per the IEC-61400-36 guideline. The rapid switching gives a large reduction in lower order harmonic current and higher order harmonics are filtered out by using filters.

3. Voltage Variation

This is due to the fluctuations in the wind turbine due to wind. The voltage variation is directly related to real and reactive power variations. The voltage variation is commonly classified as under

- Voltage Sag/Voltage Dips.
- Voltage Swells.
- Short Interruptions.
- Long duration voltage variation.

The voltage flicker issue describes dynamic variations in the network caused by wind turbine or by varying loads. Amplitude of voltage fluctuations depends on grid strength, network impedance, and phase angle and power factor of wind turbine. During voltage variations frequency is in the range 10–35 Hz. The IEC 61400-4-15 specifies a flicker meter that can be used to measure flicker directly.

4. Wind Turbine Location In Power System:

It is located where the power quality is highly influenced .Its operation and its influence on the power system depends on the structure of the network.

5. Self-Excitation of Wind Turbine Generating System:

The self-excitation of wind turbine generating system (WTGS arises a risk equipped with commutating capacitor. It provides the reactive power compensation to the induction generator. The disadvantages of self-excitation are the safety aspect and balance between real and reactive power.

6. Consequences of the Issues

Voltage variations, voltage flicker, harmonics causes the malfunctions of equipments. It leads to tripping of protection devices, damaging the sensitive equipments. Overall it degrades the power quality in the grid

B. Grid Coordination Rule

American Wind Energy Association led the effort to develop its own grid code for stable operation as per IEC-61400-21 for the interconnection of wind plants to the utility systems.According to these, operator of transmission grid is responsible for the organization and operation of interconnected system.

1) Voltage rise (u)
The voltage rise at the point of common coupling can be approximated as a function of maximum apparent power.

2) Voltage dips (d)
The voltage dips is due to startup of wind turbine and it causes a sudden reduction of voltage. It is the relative % voltage change due to switching operation of wind turbine. Where d is relative voltage.

3) Flicker
The measurements are made for maximum number of specified switching operation of wind turbine.

4) Harmonics
The harmonic distortion is assessed for variable speed turbine with a electronic power converter at the point of common connection.

5**) Grid frequency**

The grid frequency in India is specified in the range of 47.5–51.5 Hz, for wind farm connection.

III. TOPOLOGY FOR POWER QUALITY IMPROVEMENT

The STATCOM based current control voltage source inverter injects the current into the grid will cancel out the reactive part and harmonic part of the load and induction generator current, thus it improves the power factor and the power quality. To accomplish these goals, the grid voltages are sensed and are synchronized in generating the current. The proposed grid connected system is implemented for power quality improvement at point of common coupling (PCC), for grid connected system in Fig. 1

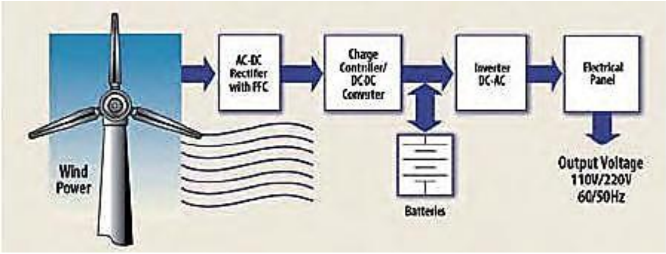


Figure. 1. Wind Energy Generating System

1) WIND ENERGY GENERATING SYSTEM.

In this configuration, wind generations are based on constant speed topologies with pitch control turbine

The generator is used in the proposed scheme because of its simplicity, it does not require a separate field circuit, it can accept constant and variable loads, and has natural protection against short circuit.

2) STATCOM (Static Synchronous Compensator)

The STATCOM (or SSC) is a shunt-connected reactive-power compensation device that is capable of generating and/ or absorbing reactive power and in which the output can be varied to control the specific parameters of an electric power system. In general it is solid state switching converter which is capable of generating or absorbing independently controllable real and reactive power at its output terminals when it is fed from an energy source at its input terminals. Specifically, the STATCOM considered in this is a voltage-source converter from a given input of dc voltage produces a set of 3-phase ac-output voltages, each in phase with and coupled to the corresponding ac system voltage through leakage reactance. The dc voltage is provided by an energy-storage capacitor. A STATCOM can improve power-system performance in such areas as the following:

1. The dynamic voltage control in Transmission and distribution systems
2. The power-oscillation damping in power transmission systems;
3. The transient stability;

4. The voltage flicker control; and
5. It also controls real power in line when it is needed.

Advantages

1) It occupies small areas.
2) It replaces the large passive banks and circuit elements by compact converters.
3) Reduces site work and time.
4) Its reponse is very fast

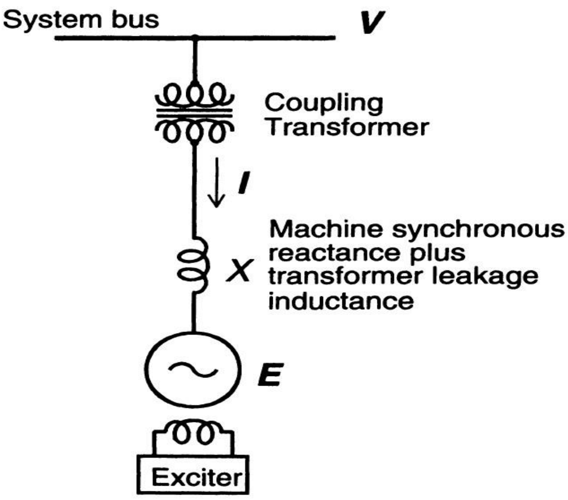


Figure 2. Basic Principle of STATCOM

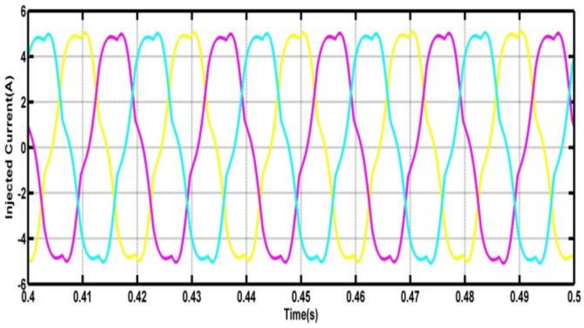
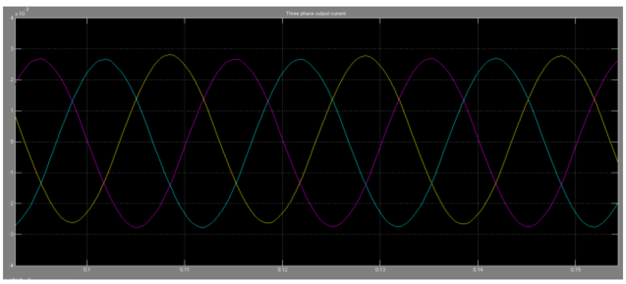


Figure 3. Three Phase Injected Inverter Current



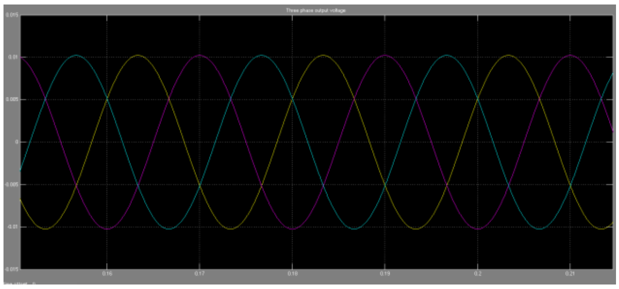


Figure 4. phase output current and voltage of grid

IV. CONTROLLER DESIGN OF PI, PD AND PID

It is possible to improve the STATCOM response by employing the PID control. It is a time consuming process but response speed, settling time and proper overshoot rate all guarantees the system stability.

In order to have effective control of active and reactive power exchange between STATCOM and ac system, suitable adjustment of phase and magnitude of STATCOM output voltages is needed. Thus power quality norms in the grid system are maintained by varying the STATCOM compensator output according to the current control strategy included in control scheme and this defines functional operation of STATCOM compensator in power system.

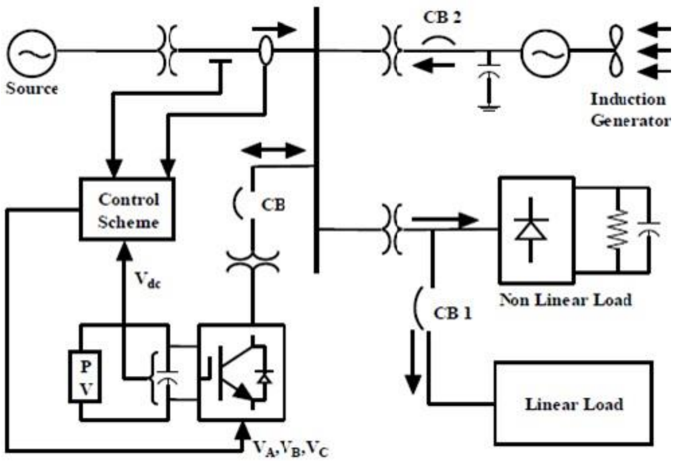


Figure 5. Schematic Model of System Operation of STATCOM Connected to Grid

The control scheme approach is based on injecting the currents into the grid using bang-bang controller. The controller uses a hysteresis current controlled technique. Hysteresis current control is a technique of controlling a VSI so that output current is generated which follows a reference current waveform. With hysteresis control limit bands are set on either side of a signal representing the desired output waveform. Controller keeps the control system variable. The switching signals generation for STATCOM control scheme is shown in Figure. Design approaches are explained below.

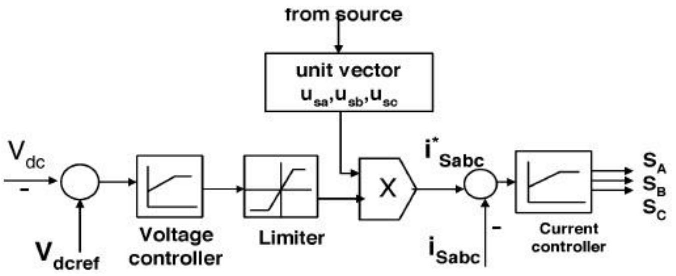


Figure 6. Control Scheme of STATCOM

1) Basic control approaches

A static (var) generator converter comprises a large number of gate-controlled semiconductor power switches (GTO thyristors). The gating commands for these devices are generated by the internal converter control (which is part of the var generator proper) in response to the demand for reactive and/or real power reference signal(s). The reference signals are provided by the external or system control, from operator instructions and system variables, which determine the functional operation of the STATCOM. The internal control is an integral part of the converter. Its main function is to operate the converter power switches so as to generate a fundamental output voltage waveform with the demanded magnitude and phase angle in synchronism with the ac system. In this way the power converter with the internal control can be viewed as a sinusoidal, synchronous voltage source behind a tie reactor (provided by the leakage inductance of the coupling transformer), the amplitude and phase angle of which are controlled by the external (STATCOM system) control via appropriate reference signal(s).

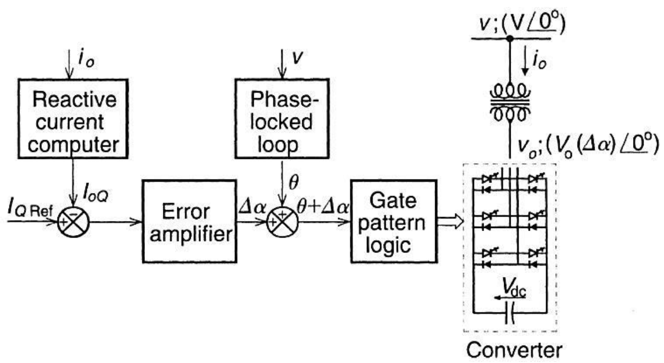


Fig.7. Main Function of the Internal Converter Control

The main function of the internal control, as stated above, is to operate the converter power switches so as to produce a synchronous output voltage waveform that forces the reactive (and real) power exchange required for compensation

2) Wind Energy Generating Model

As stated wind power injected into the network affects the voltage magnitude, its flicker, and its waveform at the point of common coupling (PCC) Figure shows the wind generator wind turbine connection to the grid.

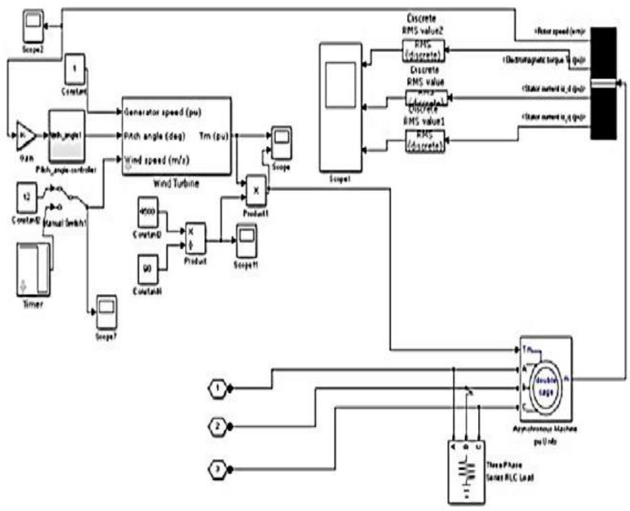


Figure 8. Simulink Model of Wind Turbine and Generator

During the normal operation, wind turbine produces a continuous variable output power, and these power variations are mainly caused by the effect turbulence, wind shear and tower shadow and of control system. The generator used in the system is induction generator. The induction generator has inherent advantages of cost effectiveness and robustness. However induction generator requires reactive power for magnetization. When the generated reactive power of an induction generator is varied due to wind, absorbed reactive power and terminal voltage of an induction generator can be significantly affected.

3) Computational Model

Simulation can take on various levels of devices and component modeling, depending on the objective of simulation. Most of the simulation examples and exercises use idealized or default component models. Designing and developing the circuit model without computer simulation are time consuming and expensive.

The modeling and simulation of power quality improvement of wind power using STATCOM with and without compensated system has to be done using MATLAB/Simulink.The parameters of the system have been chosen to represent a relatively severe case with respect to standard voltages and will cover the majority of service applications. Figure represents the generalized wind integrated system with grid having STATCOM and non-linear load.

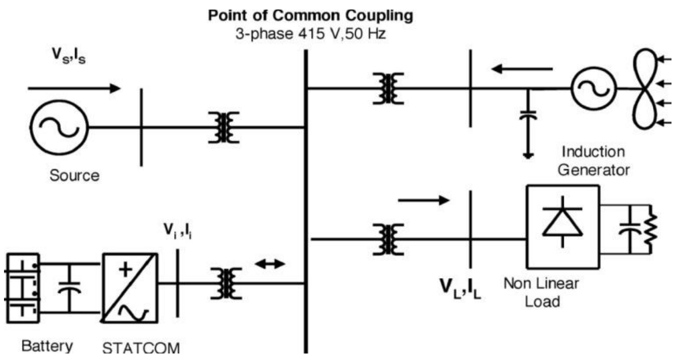


Figure 9. Grid Connected System for Power Quality Improvement

4) Simulink model of system without STATCOM

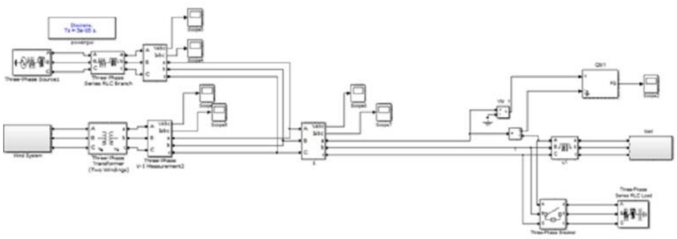


Figure 10. Simulation Block Diagram of Uncompensated System

5) Simulink model of system with STATCOM

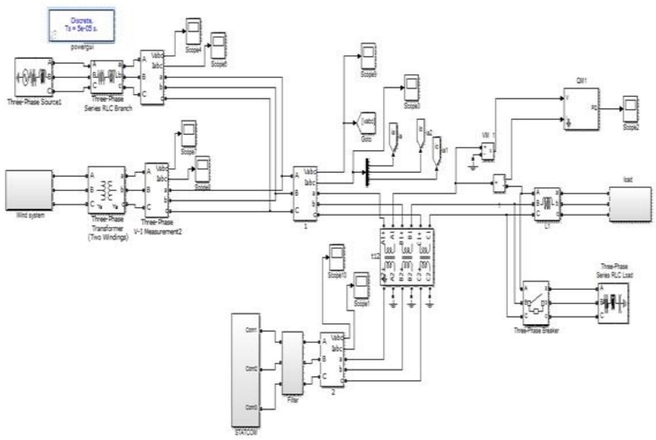


Figure 11. Diagram of Grid Integrated Wind Energy System using STATCOM

V. RESULTS AND DISCUSSION

PERFORMANCE ANALYSIS

MATLAB is a field of study, which allows one to analyse and examine a complicated or nonlinear model or process. A quantitative evaluation of power quality improvement of wind power with and without compensated system has been carried out under different operating conditions using the MATLAB / Simulink

1. Simulation Result of Uncompensated System

In this section, The performance of the compensated and uncompensated system is analyzed with the obtained results with linear and nonlinear load having STATCOM which is integrated at the point of common coupling (PCC).The figure shows the current waveform at point of common coupling without solar STATCOM of uncompensated system having the harmonics and distortion when the wind energy system connected it greatly affect the power quality of the system.

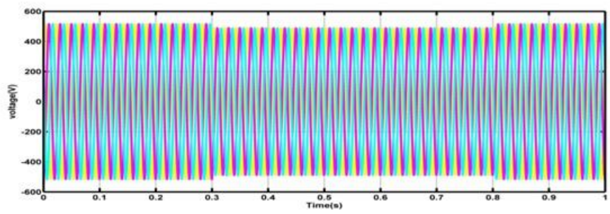


Figure 12. Voltage at PCC Without STATCOM

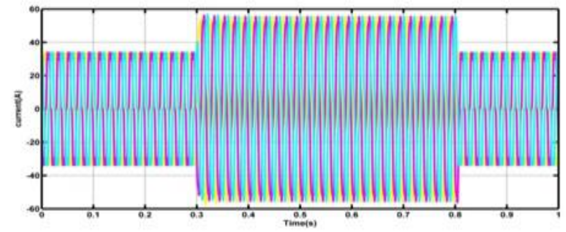


Figure 13. Current at PCC Without STATCOM

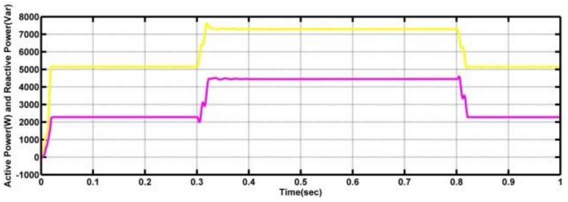


Figure 14. Active and Reactive Power Without STATCOM

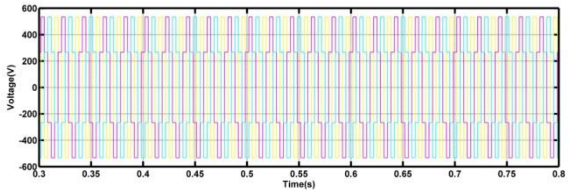


Figure 15. STATCOM Output Voltage

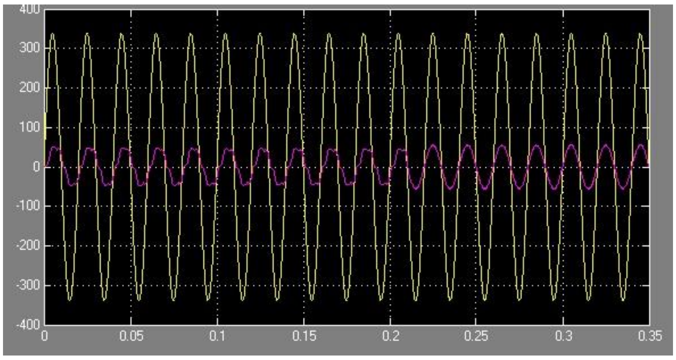


Figure 16. Supply Voltage and Current at PCC

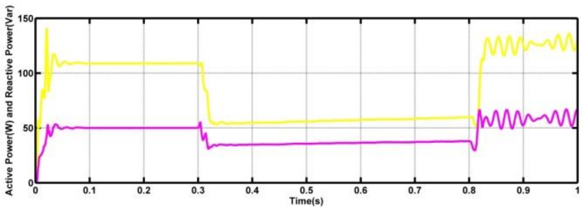


Figure 17. Active and Reactive Power with STATCOM

2. Mathematical Analysis

The following formulas are intended to be used for configuration not tabulated in the preceding chapter. The mechanical power produce by wind turbine is given as

$$Pmech=2\rho\Pi R2V3windCp$$

Where ρ(kg/m3)is the air density and R is the radius of blade(m). It is not possible to extract all kinetic energy of wind, thus it extract the fraction of power in wind, called power coefficient Cp of the wind turbine. Cp depend on types and operating condition of wind turbine. This coefficient can be expressed as a function of tip speed ratio λ and pitch angle θ. The coefficients c1 toc6 are: c1 = 0.5176, c2 = 116,c3 = 0.4,c4 = 5,c5 = 21 and c6 = 0.0068. The Cp -λ characteristics, for different values of the pitch angle , are illustrated. The maximum value ofCp (Cp = 0.48) is achieved forβ = 0 degree and forλ = 8.1. This particular value of λ is defined as the nominal valueλnom.

The mechanical power Pm as a function of generator speed, for different wind speeds and for blade pitch angleβ = 0 degree. Base wind speed = 12 m/s, maximum power at base wind speed = 0.73 pu (kp = 0.73) and base rotational speed = 1.2 pu.The maximum value of Cp (Cpmax = 0.481) is achieved for β = 0 degree and for λ = 8.1. Turbine output power is 0.8 is maximum power at base wind speed 12m/s and β = 0.The operation principle of STATCOM working through the charging and discharging of DC link capacitor.

The variation of reactive power is performed by means of a Voltage-Sourced Converter (VSC) connected on the secondary side of a coupling transformer. The VSC uses forced-commutated power electronic devices (GTOs, IGBTs or IGCTs) to synthesize a voltage V2 from a DC voltage source. The principle of operation of the STATCOM is explained on the figure below showing the active and reactive power transfer between a sourceV1and a sourceV2.

$$P = (V1V2)\sin\delta\ X$$

Where V1 is Line to line voltage of source 1,V2 is Line to line voltage of source 2,X is Reactance of interconnection transformer and filters and δ is phase angle of V1 with respect to V2

$$Q =V1(V1V2\cos\delta)\ X$$

In steady state operation, the voltageV2 generated by the VSC is in phase with V1 (δ=0), so that only reactive power is flowing (P=0). If V2 is lower than V1, Q is flowing from V1 to V2 (STATCOM is absorbing reactive power). On the reverse, if V2 is higher than V1, Q is flowing from V2 to V1 (STATCOM is generating reactive power). The amount of reactive power is given by

$$Q = (V1(V1V2)) X$$

A capacitor connected on the DC side of the VSC acts as a DC voltage source. Insteady state the voltage V2 has to be phase shifted slightly behind V1 in order to compensate for transformer and VSC losses and to keep the capacitor charged.

3. Comparison of Computational and Mathematical Approach

The mathematical and computational analysis shown as in the table given below. The maximum output power of wind turbine by the mathematical formulation is 0.8 pu whereas the computational value of maximum output power of wind turbine by computational model is 0.73 pu.

Table 1: Comparison of Results

Parameters	Without Statcom Sag	With Statcom
Voltage (V)	391	415
Current (I)	45	15
Harmonics (%)	19.99	2.52
Power Factor	0.76	0.81

Similarly the mathematical and computational analysis of inverter has to be done on the basis of parameters of DC link voltages, DC link capacitance, switching frequency, IGBT rating and load parameters.

VI. CONCLUSION

This chapter covers conclusions for the work carried out in this dissertation and it also includes future scope and application for different domain.

1. Simulink results show that hysteresis current control scheme is incorporated for the STATCOM in order to have dynamic response and its potency in curtailing the harmonics in source and PCC voltage waveform was studied by examining the waveform before and after STATCOM operation.
2. Also simulation results show that STATCOM mitigate sags/swells quickly and provides excellent voltage regulation.
3. In case due to connection of STATCOM harmonic part of source and PCC voltage is cancelled out and maintain the system voltage at its nominal level.
4. Voltage is successfully compensated, using STATCOM. The control is easy; maintain the Vd and Vq are in static manner.
5. The simulation results of uncompensated and compensated outputs are compared, and it shows that, the compensated system is improved than uncompensated system.
6. The system voltage is maintained, current reduces and harmonics of source voltage and PCC voltage is reduced from 19.99% to 2.52% which is within the limits after connection of STATCOM.
7. Thus the coherent wind generation system and STATCOM with powered BESS have shown the exceptional performance and hence this scheme can be practically implemented to meet the subsequent power demand.

Future Scope

The following points are recommended for future extension of work:

- Optimization of energy storage system of STATCOM can be done
- Other types of controllers like fuzzy controller, PWM based bang-bang controller and adaptive PI fuzzy controller can be employed in the STATCOM compensation scheme
- Effectiveness of multi-level STATCOM can be investigated
- Testing a number of deferent loads, such as thyristor loads, motor loads, active rectifier loads to verify the robustness of the loads to protect from voltage dips
- Verification of the STATCOM performance at a location of renewable energy sources grid integration system to mitigate the the power quality issues

Applications

- Static synchronous compensator is an effective and relative inexpensive FACTS device so it can be used in industrial application as well as transmission and distribution system to provide the better power quality

- Also STATCOM is the good voltage stabilizer and voltage regulator so it can be used for commercial, high voltage generating stations and domestic customer to protect expensive and sensitive equipment from power quality problems.

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